20. BEAM DUMP

A beam dump for the continuous absorption of the electron beam will be located downstream of the photon production arc. It is anticipated that the beam dump assembly will include an upstream bend magnet that directs the electrons towards a water-cooled dump located below floor level. A series of two beam windows, located between the dump and bend magnet, isolate and safeguard the beamline from contamination by the gas evolved from the dump. A partial pressure of argon gas between the windows will be monitored as a means of detecting a vacuum breech. Additional magnets to raster the beam upstream of the windows may be required to prevent excessive localized heating.

As with the other mechanical systems, the beam dump was designed to be compatible with the upgraded machine parameters of 3.1 GeV and 3 nC charge per bunch on a 10 kHz repetition rate (93 kW of beam power). The successful design a high power multi-GeV beam dump must take into consideration several factors including:

- cooling requirements
- thermal stresses
- safety – minimal reliance on active components
- radiation shielding
- activation and handling of activated components
- hydrogen generation (water cooled dumps) and handling
- fabrication feasibility and cost
- operating cost

This initial study primarily addresses thermal issues with some regard for fabrication feasibility. Estimates of the required shielding, hydrogen generation and safety issues are in progress.

The initial dump design, Figure 20-1, consists of a solid 24 cm diameter central cylinder of POCO graphite surrounded by a 2 cm thick copper outer layer. The copper is brazed to the graphite to produce a good thermal bond. The carbon/copper assembly resides within a *water jacket*. The 2-meter length of the carbon center plug is sufficient to absorb most of the energy of the electromagnetic shower. A 5 cm thick OFHC copper end plug will absorb the low energy *tail*. The combined radial thickness of copper and carbon is sufficient to absorb more than 99% of the energy in the transverse direction. Water flowing at a modest rate over the surface of the copper removes 93 kW of heat on a steady-state basis.

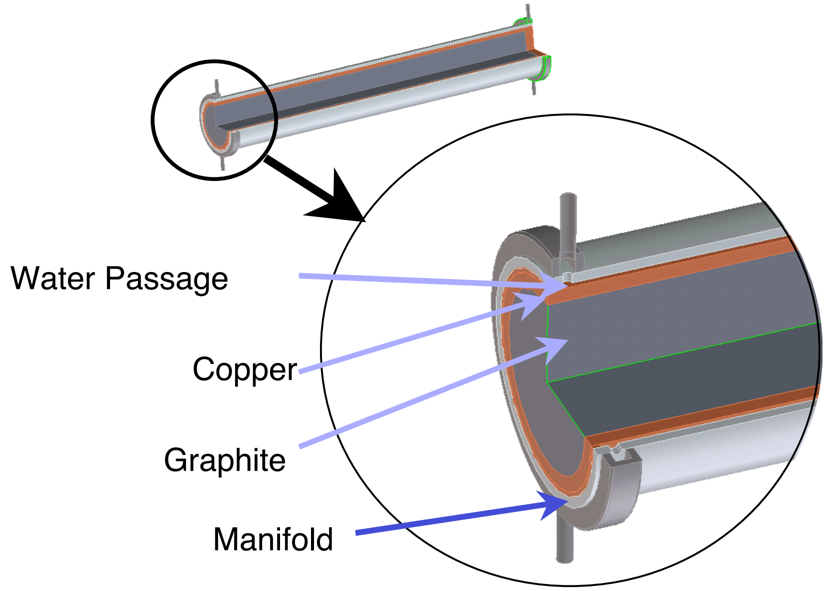

Figure 20-1 Beam absorbing assembly.

Carbon has the advantage of a relatively long (physical) radiation length and excellent thermal conductivity. Pure aluminum has roughly twice the thermal conductivity but less than half of the radiation length of carbon whereas copper has about 4 times the conductivity but less than 1/10 the radiation length. A long physical radiation length leads to a broad longitudinal electromagnetic shower profile and an enhanced radial power deposition. Diffuse longitudinal energy absorption spreads the heat over a greater effective surface area for cooling (at the perimeter) and reduces the peak temperatures. High thermal conductivity allows for a greater radial path length from heated core to cooled surface (for a given peak temperature) and thus a lower power density at the convection boundary due to increase in outer surface area with radius.

A comparison of the power deposition for three candidate absorber materials is shown in Figure 20-2. Power deposition profiles were determined using the formulas for electromagnetic cascades in European Physical Journal C, Particles and Fields [1].

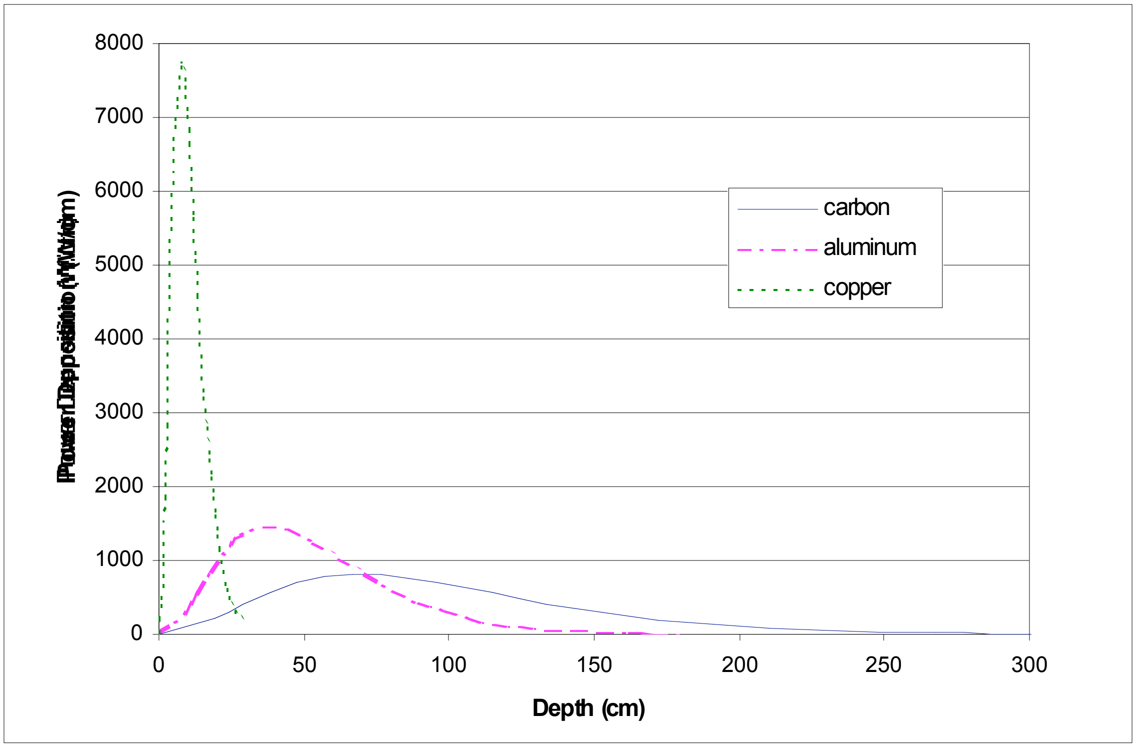

Figure 20-2 Power deposition profiles of an electromagnetic cascade in carbon, aluminum and copper for a 3.1GeV, 93kW electron beam.

The transverse development of electromagnetic cascades scales with the Moliere radius, R_M given by [1]

$$R_M = X_0 E_S / E_C \tag{1}$$

where E_S = 21.2 MeV, Z = atomic weight, X_o is the radiation length, and

$$E_C = \frac{610\,\text{MeV}}{Z+1.24} \tag{2}$$

The critical energy, E_C, is the energy at which the ionization loss per radiation length is equal to the electron energy [2]. Approximately 90% of the energy is contained within one R_M and 99% is contained within 3.5 R_M. For copper R_M = 1.5 cm and for carbon R_M = 4.8 cm. To approximate the transverse power deposition, a single Gaussian distribution with $\sigma = R_M / 1.65$ (90% of the swept volume is contained within a radius of R_M). Setting the area under the transverse profile equal to the power dissipation at a given depth of absorber gives the volumetric power deposition at any point in the absorber volume. The actual distribution starts as a narrow core and broadens as the cascade develops so the assumed constant transverse profile underestimates the volumetric power density over the initial length of absorber. Further refinement in this area is required to determine if the electron beam must be rastered.

The calculated absorbed power density in carbon peaks at roughly 5 W/cm^3 and falls off radially to less than 0.5 W/cm^3 at a radius of 16 cm. To estimate the temperature rise and thermal stress the power density was applied to an axisymmetric FEA model (ANSYS). The resultant temperature and stress plots are shown in Figures 20-3 and 20-4.

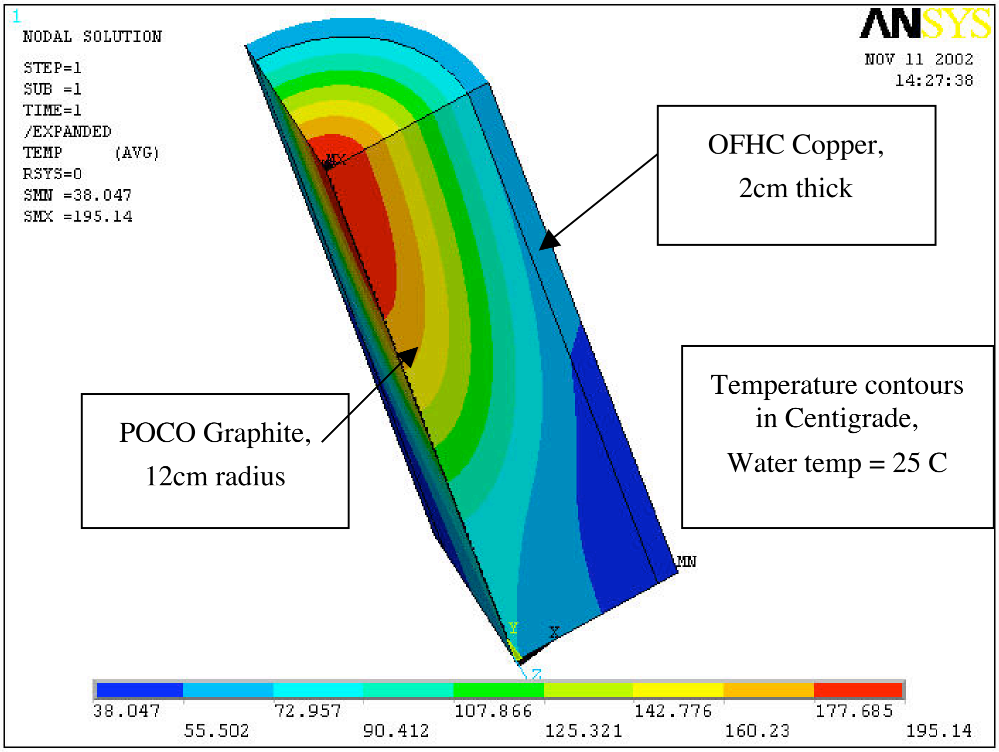

Figure 20-3 Temperature profile for carbon/copper beam dump over the first 75 cm. Convective heat transfer coefficient of 2000 W/m^2-C applied to outer surface.

The model encompasses the first 75 cm of absorber length, corresponding depth of the energy deposition peak. A symmetry boundary condition was applied at the x = 75 cm end to take advantage of the near symmetry in the longitudinal energy deposition profile.

The convective heat transfer coefficient of 2000 W/m^{2}C is consistent with 25 ^{o}C water flowing over the surface at 0.37 m/s. This can be achieved by passing water at 2 l/s through a concentric passage having an annular gap of 6 mm. Note that the calculated peak.

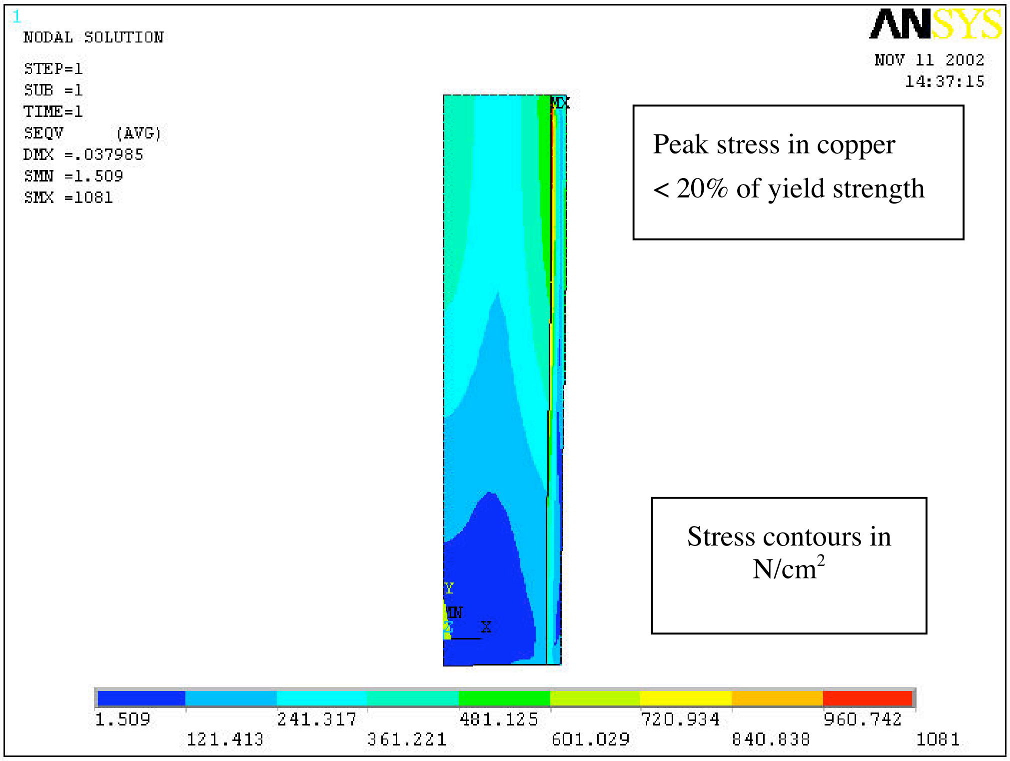

Figure 20-4 Stress contours (von Mises equivalent) for a carbon/copper beam dump, first 75 cm.

temperature of the graphite is very modest and that the temperature at the convective boundary (in contact with water) is well below boiling.

The structural boundary conditions mirror the thermal case with a symmetry boundary applied at x = 75 cm. The thermal stresses are very modest in comparison to the tensile strength of POCO graphite of 3500 – 7000 N/cm^2 (5000-10000 psi) and the yield strength of annealed OFHC copper of 7000 N/cm^2 (0.2% offset).

On the basis of this initial study, the ability to construct a beam dump capable of withstanding the power of the proposed re-circulating linac running at an upgraded energy and elevated bunch charge (3.1GeV, 3 nC) appears feasible. Peak temperatures and thermal stresses are relatively low for a reasonably sized water-cooled absorber constructed from carbon and copper. The design of the upstream windows and power dissipation at shower incipience may require that the beam be rastered. Radiation shielding, activation and cost issues are yet to be addressed.

REFERENCES:

[1] European Physical Journal C, Particle and Fields Vol. 15, pp.167-171, Nov 1, 2000.